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Response of a Global Spectral Model for Simulation of Indian Summer Monsoon Rainfall

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Abstract: The present work highlights response of a global spectral model T80L18 with respect to Indian summer monsoon rainfall (ISMR) during 8 years period of 1996-2003. The model performance is evaluated for day-1, day-3 and day-4 retrospective 24-hour accumulated rainfall forecasts from 0300 UTC to the next day 0300 UTC using in-situ rainfall observations of 4491 stations. The model performance is evaluated by assessing: (i) percentage departure and root mean square error (RMSE) of seasonal rainfall forecast, (ii) coefficient of variation (CoV) of seasonal rainfall forecast and observation, along with percentage departure of monthly rainfall forecast and (iii) model performance during a drought and a normal year of 2002 and 2003, respectively. Generally, it is noted that the T80L18 model underestimated high rainfall and overestimated low rainfall, however, with increasing forecast duration prediction over low rainfall areas improved. The model RMSE over central and western India is found to increase with increasing forecast duration; however, the same was found to decrease over Jammu and Kashmir. The CoV of day-1 rainfall forecast is found to be low over all India in comparison to the observed data. In the case of model performance evaluation during a drought and a normal year of 2002 and 2003, it is noted that the model produced higher rainfall over the rainfall deficit regions of observed distribution; whereas the heaviest observed rainfall region (>250 cm) is not well resolved by the model. In general, the T80L18 model performance is noted to be better over central India for mean seasonal rainfall prediction.

Keywords: Global T80L18 model; Indian summer monsoon rainfall; Forecast skill.

Introduction

The south-west monsoon over the Indian subcontinent during 122 days of June to September (JJAS) is generically associated to a marked change in the regional scale wind system due to differential heating between land and surrounding oceans (Das, 1998). The two dominant atmospheric features related to the onset of monsoon are (i) formation of pre-monsoon heat-low over the arid and semi-arid regions of northwest India, Pakistan and Arabia and (ii) formation of pre-monsoon equatorial low-pressure zone near 5ºN. With the progression of monsoon, the equatorial low merges with the heat low and forms monsoon trough. Once the monsoon trough is located over northern India along a northwest to southeast direction, moisture-laden trade-winds from the Arabian Sea and Bay of Bengal produce some of the heaviest seasonal rainfall over the Indian subcontinent. Above 80% of rainfall over India is from the south-west monsoon of June to September (Jain and Kumar, 2012). The summer monsoon rainfall has significant spatio-temporal, intra-seasonal and inter-annual variability (Shukla, 1987; Goswami and Ajay Mohan, 2001; Mukherjee et al., 2011a; Mukherjee et

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al., 2016). Consequently, the Indian socio-economy is highly dependent on the annual southwest monsoon rainfall having significant spatio-temporal, intra-seasonal and inter-annual variability. The inter-annual variability has a coefficient of variation of only 9% over India (Mishra et al., 2012). Yet, this small variability has a strong significant impact on agricultural production, water resource management, etc.

Therefore, the long-range forecast of Indian summer monsoon rainfall (ISMR) is of considerable interest to the public in general and the scientific community in particular. At many research centres across the globe, different numerical weather prediction models are simulated for the prediction of Indian summer monsoon in operational mode quantitatively at monthly, seasonal, intra-seasonal and inter-annual time scales, and global spectral models are of particular interest in this regard (Gadgil et al., 1992; Palmer et al 1992; Kar et al., 2001; Roy Bhowmik and Prasad, 2001; Mohan et al., 2003). However, the ISMR forecast quality, which is determined by the degree of similarity between the model forecast and observation (Murphy, 1993), in general, is quite low due to the poor skill of a model. Furthermore, due to substantial error propagation within the global models, long and medium-range model forecast skills in tropics deteriorate significantly from day-3. Therefore, instead of using medium and long-range forecast through a global model, various regional models are simulated in an operational mode for short-range forecast of ISMR (Azadi et al., 2001; Bhaskar Rao et al., 2004; Dash et al., 2009; Dutta et al., 2009). However, long and medium-range forecast using a global model is highly necessary for socio-economic reasons, particularly for agriculture. Improvement of the global climate model is also crucial for the reduction of forecast uncertainties. Moreover, forecast verification is also necessary to understand bias associated with the model. Improvement of global model forecast skill can be done particularly by improving physical parameterization schemes, increasing horizontal resolution or spectral wave numbers, data assimilation processes, and better initial and boundary conditions.

Present-day numerical weather prediction is progressing steadily due to the availability of enormous computational facilities and huge data from satellite observation. Subsequently, a significant development was made in the global model performances including global spectral models. In this regard, the global spectral model with the first 80 waves (T80L18) remains to be of special interest despite significant advance in spectral model resolution (such as T959 of Japan Meteorological Agency High-resolution model). The T80L18 model is being used by many researchers as a primary model for the long and medium-range forecast of the Indian summer monsoon, and T80L18 model outputs are used as an input to the regional models' forecast, for example, Dash et al. (2002) studied the Indian summer monsoon rainfall for July using T80L18 model with three different convective parameterisation schemes. Subsequently, the T80L18 model rainfall forecast was assessed with respect to observations for three diverse regions of India, such as West Bengal, Andhra Pradesh and Rajasthan using 5 years average data from 1997 to 2001 by Mandal et al. (2007). Roy Bhowmik and Prasad (2008) tried to improve the Indian monsoon rainfall forecast using an operational mode limited area model having a compatible resolution initial and boundary condition data from the T80L18 model. Dutta et al. (2009) compared the impact of downscaling on seasonal monsoon rainfall using rainfall products from T80L18 and MM5 models. Kar et al. (2011) examined the ensemble spread of systematic error in a higher resolution spectral model T170 in association with the existing T80L18 model during the prediction of Indian summer monsoon rainfall. Ballav et al. (2014) examined the inter-annual monsoon rainfall variation of 1996-1998 as obtained from the T80L18 model over the Himalayan region. However, a detailed performance analysis of the T80L18 model forecast of rainfall at different forecast time scales over entire India for 8-year period is not attempted yet.

Therefore, the overarching aim of this present study is to quantitatively evaluate retrospective forecasts of ISMR from 1996 to 2003 from a global T80L18 model. The quantitative evaluation of model past forecasts is made by assessing: percentage departure and root mean square error (RMSE) of forecast rainfall; coefficient of variation (CoV) of observed and forecast rainfall; percentage departure of monthly rainfall for forecast data; and by evaluating model performance during a drought and a normal year of 2002 and 2003, respectively. Moreover, the evaluation of model performance is carried out with the increasing length of the forecast duration.

Model, Data and Methodology

Model Description

The global spectral model with first 80 waves (T80L18), as developed by National Centre for Environment Protection (NCEP), USA (Kanamitsu et al., 1991), and subsequently modified by the National Centre for Medium-Range Weather Forecasting (NCMRWF), Ministry of Earth Science (MoES), India, was used in this study to forecast daily monsoon rainfall. The '*retrospective or past forecast*' term is synonymously used in this study as '*forecast*'. The detailed description of the T80L18 improved model is provided in Purohit et al. (1996) and Basu (2003). The model had 18 vertical sigma levels. The entire globe was covered by 256 × 128 grid points with a resolution of 1.406° × 1.406°. The model provided rainfall at every 15 minutes interval starting from 0000 Universal Standard Time (UTC) and ending at 7th forecast day. The T80L18 model configuration used in this study is presented in Table 1. Data for the model initial condition were obtained from the Global Telecommunication System computer of India Meteorological Department (IMD), New Delhi; prepared through in-situ or remote sensing observations. Kuo (1974) scheme and Tiedtke (1983) formulation were used, respectively, for cumulus and shallow convection. In the case of large-scale precipitation, saturation-based modified Manabe et al. (1965) scheme was used. Results presented here are only for day-1, day-3 and day-4 forecasts of 24 hours accumulated rain during 0300 UTC of day-1 to the 0300 UTC of day-2. The model output was considered for 8 years from 1996 to 2003.

Data Description

Before analysing the model performance, daily rains during the 122 days summer monsoon season from a total number of 4491 stations across India during 1995-2004, as available from the National Data Centre, IMD, Pune, India, were used to quantify observed climatological variability of ISMR. However, the number of station data varied year-to-year. Rainfall for each day was produced using 24 hours accumulated value of 0300 UTC of day-1 to 0300 UTC of day-2. For comparison with the model output, only 8 years of observed data from 1996 to 2003 were used, whereas 10 years of observed data were used to produce average observed seasonal rain, over India, with standard deviation.

Table 1: Details of the T80L18 global spectral model similar to the one described in Dutta et al. (2009)

Components	*Specifications*
Grid	
Horizontal	Global spectral T-80. Total 256 × 128 grid points
Vertical	18 Sigma layers
Topography	Mean
Dynamics	
Horizontal transformation	Orszag's Technique
Vertical difference	Arakawa's energy conserving scheme
Time difference	Semi-implicit with 900 sec time-step
Time filtering	Robert's method
Horizontal diffusion	Second order over quasi-pressure surfaces, scale selective
Physics	
Surface fluxes	Monin-Obukhov Similarity
Turbulent diffusion	K-theory
Radiation	Short wave – Lacis and Hansen, Harshbhardhan; long wave – Fels and Schwarzkopf
Deep convection	Modified Kuo scheme
Shallow convection	Tiedtke formulation
Large-scale condition	Saturation based modified Manabe'e scheme
Clouds	Slingo's scheme
Rain evaporation	Kessler's scheme
Land surface process	Pans's (3-layer soil temperature, bucket hydrology for soil moisture) method
Air-sea interaction	Roughness length (Charnock relation), SST, SH & LH (bulk formula)

Grid Box Preparation over India

The T80L18 spectral model had a total of 135 Gaussian grid boxes covering entire India as shown in Figure 1. Around each grid point of the model, a grid box was constructed having dimensions of 1.406° × 1.406° (~154.7 km × 154.7 km). Average rainfall observation from different stations within a grid box was constructed using Thiessen Technique as described in Mandal et al. (2007). Grid box No. 1 was located at the left corner of the northern most India and the grid box number increased row-wise. The rainfall variability of these gridded products were analysed in detail in the following sections.

Distribution of Average Observed Seasonal Rainfall

The spatial distribution of 'average observed monsoon seasonal total rainfall' of 1995-2004 within the 135 grid boxes over India is presented in Figure 2. The 'average observed monsoon seasonal total rainfall' was estimated by simply calculating the arithmetic mean of seasonal total rainfall for the period of 1995-2004. Subsequently, variations in the average observed monsoon seasonal total rainfall was assessed following the IMD classification of rainfall category as: category-I: seasonal total rainfall <250 mm; category-II: 250 < seasonal total rain < 500 mm; category-III: 500 < seasonal total rain < 750 mm; category-IV: 750 < seasonal total rain < 1000 mm; category-V: 1000 < seasonal total rain < 1500 mm; category-VI: 1500 < seasonal total rain < 2000 mm; and category-VII: seasonal total rain > 2000 mm. The rainfall distribution was further assessed over meteorological sub-divisions of India as: (i) northwest India: Jammu and Kashmir, Himachal Pradesh, Punjab, Uttrakhand, Uttar Pradesh, Haryana and Rajasthan; (ii) northeast India: Bihar, Jharkhand, West Bengal, Assam, Arunachal Pradesh, Nagaland, Manipur, Mizoram, Tripura, Meghalaya and Sikkim; (iii) central India: Gujarat, Maharashtra, Madhya Pradesh, Chhattisgarh, Orissa; and (iv) peninsular India: Andhra Pradesh, Tamil Nadu, Karnataka, Kerala.

Maximum seasonal rainfall (≥ 2000 mm, category VII) was observed only in parts of northeastern and peninsular India covering seven grid boxes (three grid

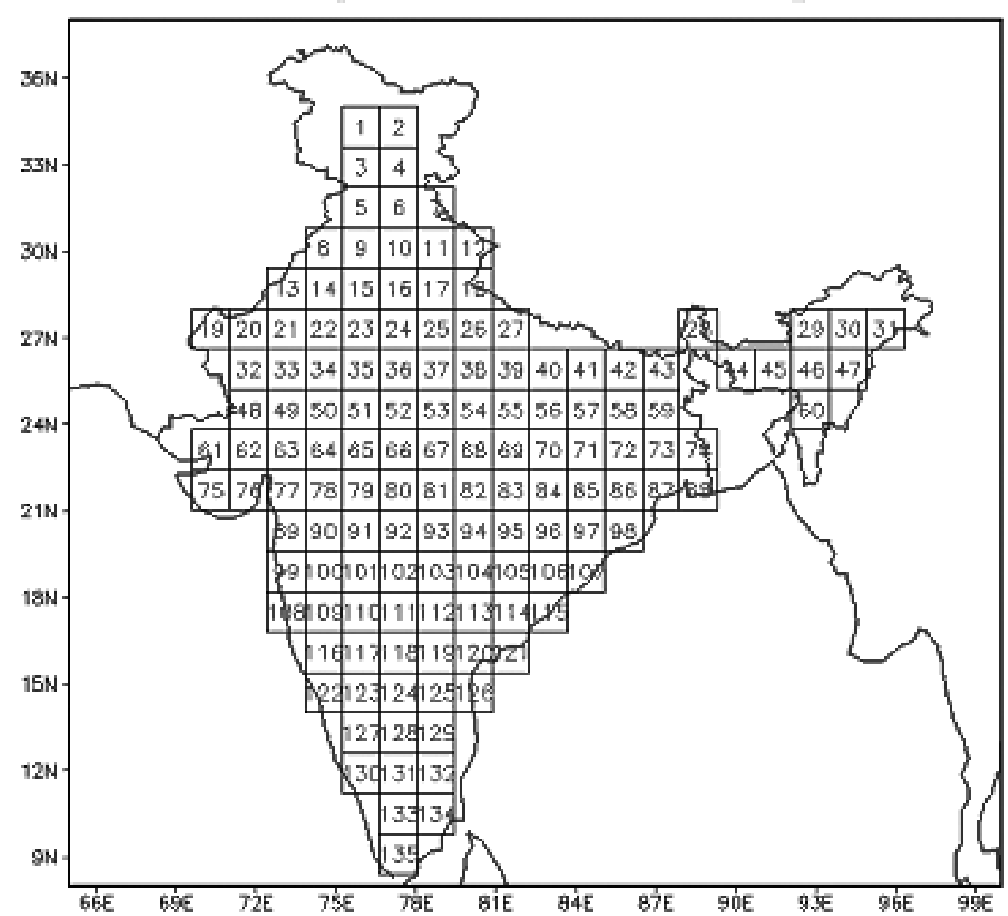

Figure 1: Grid boxes considered over India are represented. The total number of grid boxes is 135.

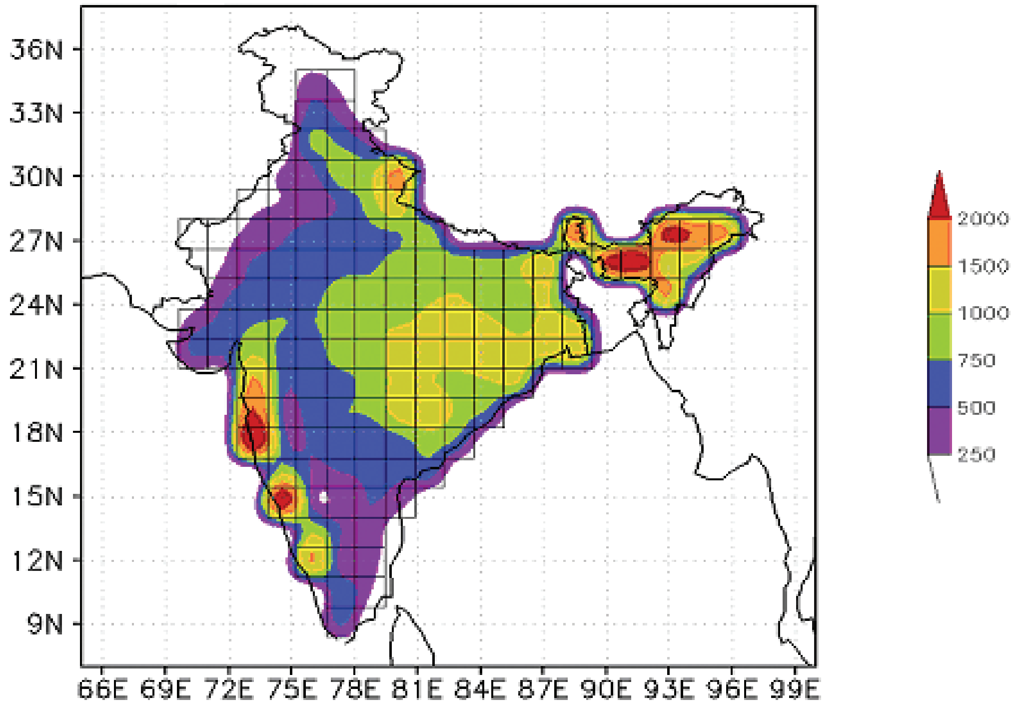

Figure 2: Ten years (1995 to 2004) average of observed monsoon seasonal rainfall (mm) over India.

boxes over peninsular India and four grid boxes over northeastern India). The category VI rainfall (1500 < seasonal total rain < 2000 mm) was observed in parts of Uttarakhand (northwest India), Arunachal Pradesh, lower Assam in northeastern India, the northern region of coastal Maharashtra including parts of Gujarat and Kerala region. The category VI rainfall occurred over six grid boxes. The category V rainfall (1000 < seasonal total rain < 1500 mm) covered only eastern India over 21 grid boxes. Most of central India (i.e., Maharashtra, Madhya Pradesh, Chhattisgarh, Gujarat and Orissa) was covered by the category III and IV rainfall (500 < seasonal total rainfall < 1000 mm) covering 75 grid boxes. The category II rainfall (250 < seasonal total rainfall < 500 mm) covered mainly northernmost part of India, part of western Rajasthan and part of south India over 20 grid boxes. Poorest rainfall below 250 mm (category I) mainly occurred over Ladakh, desert part of western Rajasthan and the southeastern part of Tamil Nadu over six grid boxes.

Standard Deviation of Ten Years Average Observed Seasonal Rainfall Over India

To provide an overview of the departure of observed rainfall from the decadal mean of seasonal total rainfall of India, the average standard deviation (SD), estimated from 1995 to 2004, is provided in Figure 3. It can be noted from Figure 3 that the rainfall fluctuation was minimum (within 100 to 200 mm) over central India, some part of peninsular India and northwest India covering 83 grid boxes. When examined among high rainfall areas (>2000 mm) like northeastern states of Sikkim, Meghalaya, Assam, a foothill of Himalayas and coastal western Ghats covering five grid boxes of the model domain, the rainfall fluctuation was much higher (>400 mm) in comparison to the other regions of India. Rest of the country, i.e., Gangetic West Bengal, Orissa, Chhattisgarh, Kerala, part of northern Maharashtra, the eastern part of Gujarat and Rajasthan, and part of far northeast India had moderate rainfall fluctuations, i.e., SD having a range of 200 mm to 400 mm covering 46 grid boxes of the model domain.

Monthly Mean Observed Rainfall Distribution

Ten years (1995 to 2004) average monthly mean observed monsoon rainfall distribution over India is presented in Figure 4 (a-d). It is to be noted that the rainfall intensity was high over entire India during July and August compared to June and September. One important feature was the low monthly variation of rain in the rain shadow region of peninsular India. Over northeast India, heavy rainfall occurs in June and July (above 600 mm), while rainfall varies between 200 mm and 600 mm in August and September.

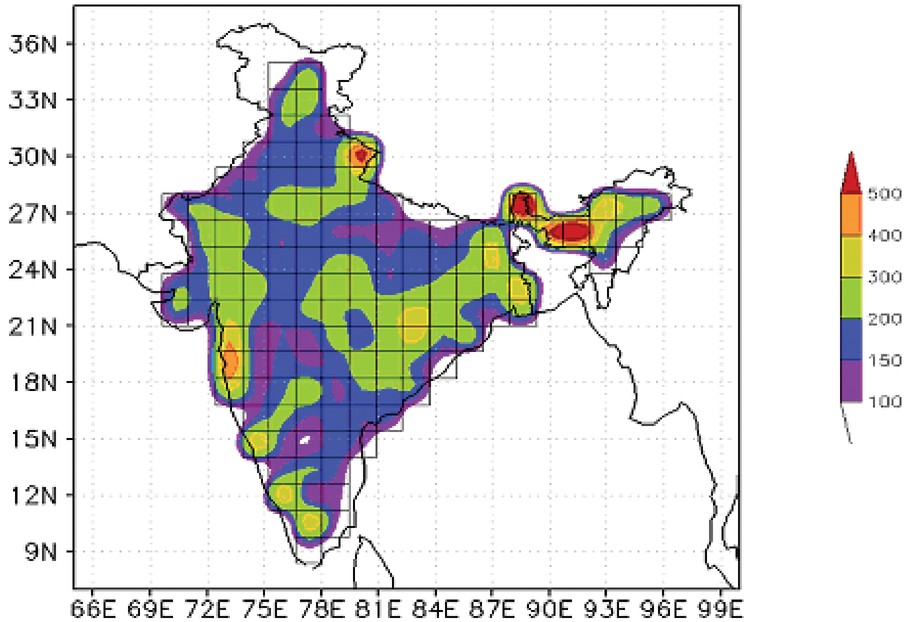

Figure 3: Standard deviation of ten years (1995 to 2004) average observed seasonal rainfall (in mm) over India.

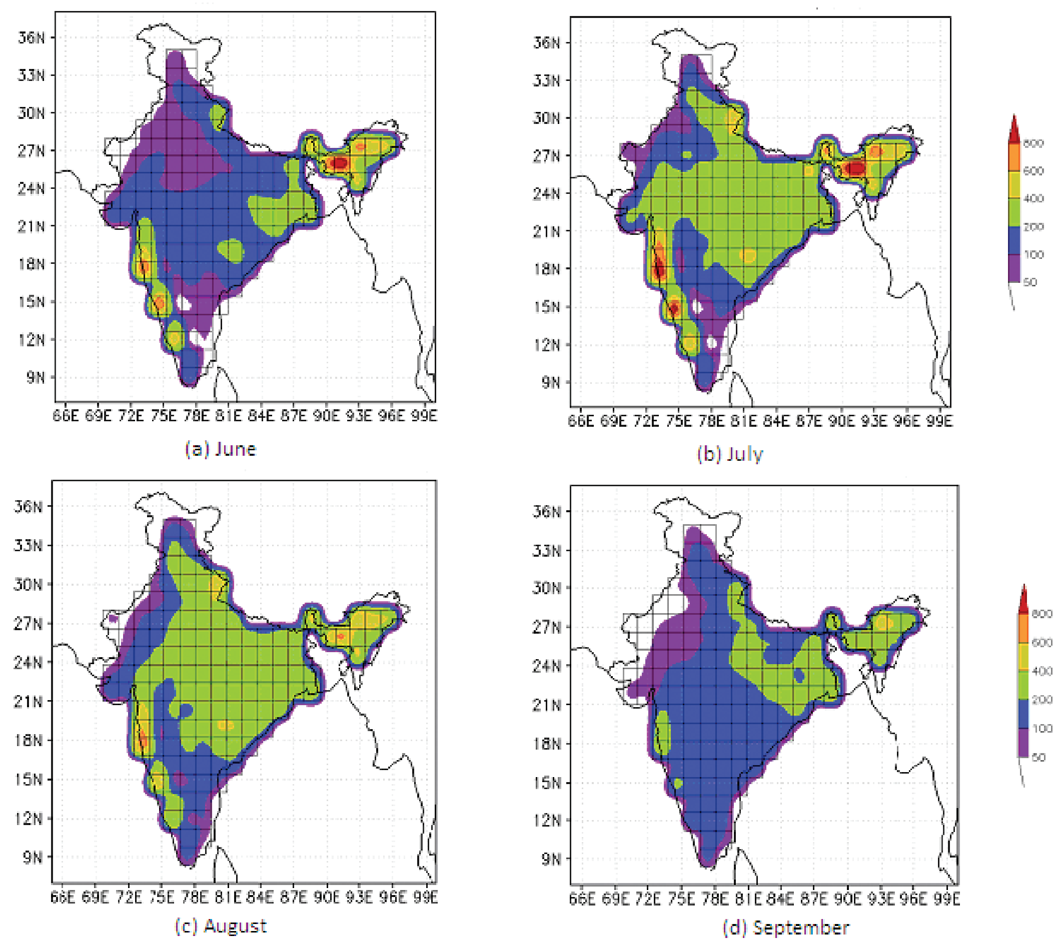

Figure 4: Subplots a-d represent the 10 years average monthly mean observed rainfall during summer monsoon season. Panels (a), (b), (c) and (d) represent the same for June, July, August and September, respectively.

Results

Performance of model forecast (i.e., forecast length from day-1 through day-4) is evaluated in this section by analysing (i) percentage departure (PD) and root mean square error (RMSE) of forecast rainfall; (ii) coefficient of variation (CoV) of observed and forecast rainfall; (iii) percentage departure (PD) of monthly rainfall for forecast data; and (iv) model performance during a drought and a normal year of 2002 and 2003, respectively. Detail outcome of these analyses is given below.

Percentage Departure of Seasonal Rainfall for Day-1, 3, 4 Forecast

To quantify the average departure of seasonal rainfall from the normal value at any place over India in the model forecast, the percentage departure of forecast rainfall was quantified. Here, day-1 forecast implies the 24 hours cumulative rain in mm based on the initial condition of the previous day, i.e., initial condition of 31st May of a year would forecast rain of 1st June of the same year. Similarly, day-3 (72 hours) forecast and day-4 (96 hours) forecast imply forecast valid on 1st June of a year on the basis of initial condition of 29th May and 28th May of the same year, respectively. The absolute percentage departure of day-1, day-3 and day-4 forecast rainfall for each of eight years of average data from 1996 to 2003 was considered over individual grid boxes and presented in Figure 5 (a-c). Percentage departure (*PD*) of each year was estimated using the following formula:

$$PD = \frac{\text{Seasonal model output} - \text{Seasonal observed value}}{\text{Seasonal observed value}} \times 100 \qquad (1)$$

The T80L18 model was noted to have high *PD* when compared with observed rainfall. It can be noted from the day-1 forecast that central India and part of far eastern states fall within 25% departure of the long term mean over 34 grid boxes. Around 72% of India was covered within 25% to 50% departure, rest of central India, northeastern states, coastal Maharashtra, part of Rajasthan, Punjab, Haryana, Gujarat, Bihar, part of Uttar Pradesh and Chhattisgarh was within this range. The northernmost part of the country, the desert of western Rajasthan, part of Jharkhand, Maharashtra

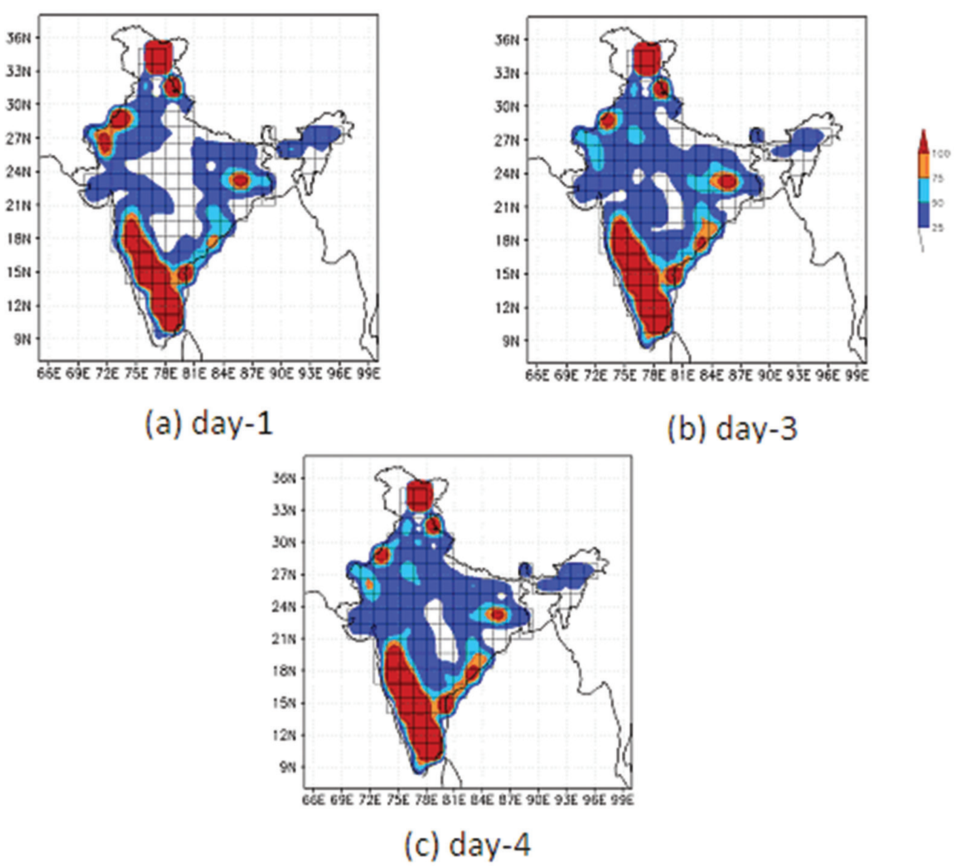

Figure 5: Subplots a-c represent percentage departure of day-1 (24 hours), day-3 (72 hours) and day-4 (96 hours) forecasts of summer monsoon seasonal average rainfall (mm) over India from 1996 to 2003, respectively.

and peninsular India was noted to have a departure of above 50%. A total of 38 grid boxes were covered in this category.

The day-3 and day-4 forecasts were not much different in general. However, the difference was conspicuous over Uttar Pradesh. Regions having very high *PD* (>100%) did not undergo almost any change for day-3 and day-4 forecasts. In case of day-3 and day-4 forecasts, *PD* < 25%, 25% to 50% and > 50% were covered by 20 and 15, 71 and 74, 44 and 46 grid boxes, respectively. Finally, it can be concluded that the model underestimated heavy rainfall, overestimated low rainfall and well predicted the medium rainfall.

Forecast RMSE of Seasonal Total Rainfall for Day-1, 3 and 4

To represent model performance in terms of error statistics, root mean square error (RMSE) of model seasonal output with respect to observed seasonal rainfall was evaluated over each grid box taking 8 years of data. The RMSE was calculated as follows:

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n} (p_i - o_i)^2}{n}} \quad (2)$$

where p_i and o_i are the predicted and observed values for i-th time. The RMSEs of day-1, day-3 and day-4 simulations are presented in Figure 6a-c, respectively. It can be noted from the figures that with increasing forecast length, RMSE over central India and western India gradually increased, i.e., forecast skill decreased. Over central India, the RMSE was found to vary between 100 and 300 mm for the day-1 forecast, and RMSE increased from 300 to 500 mm for day-3 and reduction in RMSE over Jammu and Kashmir region with the increasing forecast length (i.e., day-1 to day-3 and finally day-4). A particular reason for such error propagation behaviour is not investigated here. Moreover, RMSE, irrespective of forecast length, was also noted to be high over those regions where *PD* was high.

Coefficient of Variation of Forecast and Observed Rainfall for Day-1

To examine the ISMR forecast quality by T80L18 with respect to observations, the coefficient of variation (CoV) of observed and day-1 forecast rainfall distribution over India was estimated for eight years (1996 to 2003) and mean CoV of JJAS rainfall was produced (Figure 7a, b). The CoV was calculated taking the ratio of standard deviation (σ) and mean value (μ) of rainfall as follows:

$$\text{CoV} = \frac{\sigma}{\mu} \times 100 \quad (3)$$

Figure 7a shows that CoV for the observed rainfall was very high (>60) for the rain deficit region of Rajasthan and Jammu and Kashmir; whereas CoV was moderately high in the region of rain shadow areas of peninsular India, part of Rajasthan and Gujarat (between 30 and 60). Rest of India, i.e. central India, part of northwestern India and entire northeastern India, was noted to have comparatively low CoV (below 30). However, in case of day-1 retrospective forecast rainfall, CoV was found to be low all over India in comparison to the observations (Figure 7b). The model CoV was found not to change much in day-3 and day-4 forecast rainfall (not presented in the figures).

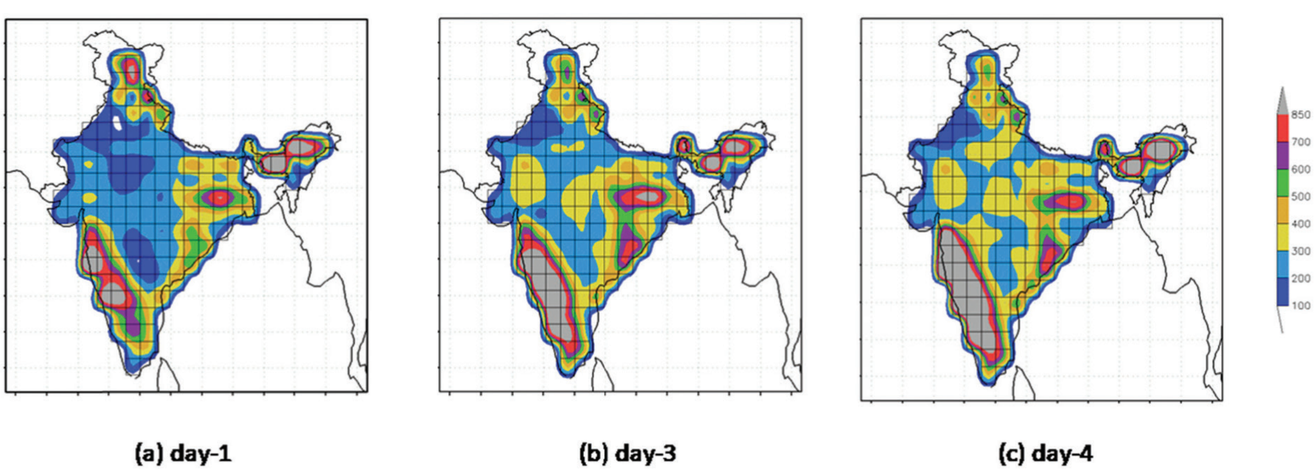

Figure 6: Subplots a-c represent the root mean square error (in mm) between the model forecast of day-1, day-3, day-4 and observed seasonal rainfall over India taking eight years of data for summer monsoon seasons.

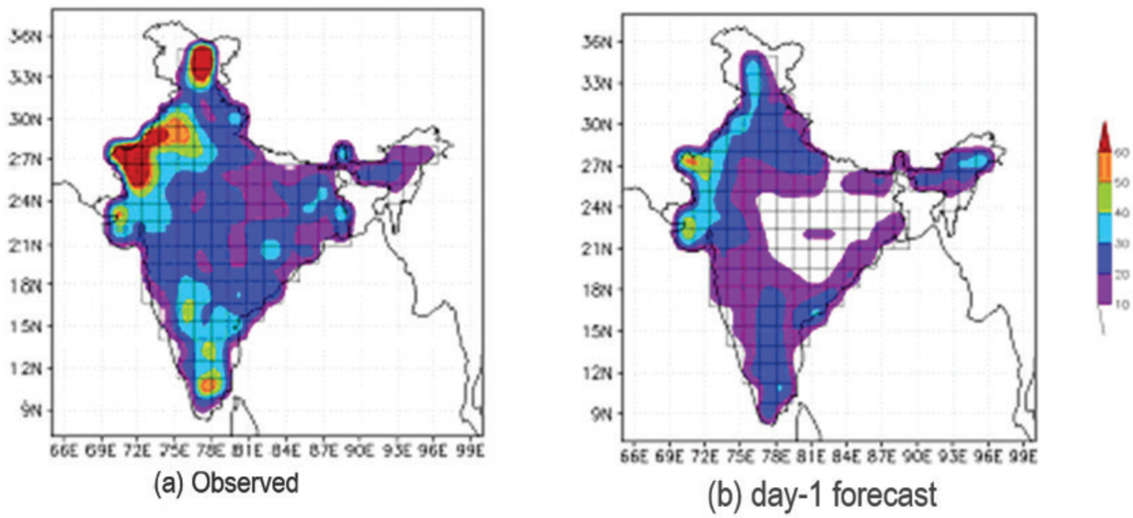

Figure 7: Subplots a-b represent the coefficient of variation of eight years average summer monsoon rainfall where panel (a) represents observed rainfall and panel (b) day-1 forecast rainfall.

Percentage Departure of Monthly Mean Rainfall for Day-1, 3 and 4 Forecast

Figures 8 (a-l) illustrate the percentage departure of monthly mean day-1, day-3 and day-4 forecast rainfall for the months of JJAS. The percentage departure was always below 25% for all the months of summer monsoon season over Central India. Less than 25% percentage departure was also noted for selected regions of East and West India during July and August, i.e., the model error decreased in these months. The maximum percentage departure (> 100%) was noted for peninsular India (Kerala, Karnataka and Tamil Nadu) and Jammu and Kashmir in June and July. However, the percentage departure was found to decrease over peninsular India in August and September. No significant change in percentage departure was noted with the increasing length of the forecast.

Model Performance in Normal and Drought Monsoon Years

The model performance of two consecutive monsoon seasons of 2002 and 2003, which are reported as drought and normal monsoon years, respectively, is evaluated in this section. All India total monsoon rainfall of 2002 was approx. 700.0 mm, a seasonal rainfall departure of 21.5% (Bhat, 2007) with an average rainfall of June-August 7.1 mm/day (Mukherjee et al., 2011b), much less than the normal years having rainfall within 10-15 mm/day. The fact that the rainfall in July 2002 was recorded as lowest in most parts of India over the past 102 years, makes it special and IMD declared 2002 as drought year. Moreover, the 2002 drought was also associated with El Nino event.

Figure 9(a) shows the observed monsoon rainfall distribution of 2002. Figure 9 (b-d) represent model simulated monsoon rainfall distribution over India in 2002. It can be seen that monsoon rainfall was below normal for most of peninsular India (Lee-side of the Western Ghats, rain shadow region of Tamil Nadu) compared to the rainfall distribution of the normal year 2003. The model produced higher rainfall over the rainfall deficit regions of observed distribution; whereas the heaviest observed rainfall region (>250 cm) was not well resolved by the model during 2002. It was even down to 70 cm of rainfall in few areas. Furthermore, change in rainfall distribution was not conspicuous with the increasing length of the forecast duration.

Figure 10a shows the observed rainfall distribution of the normal monsoon year 2003. It can be seen that peninsular India, i.e., heavy rainfall zone in coastal Western Ghats mountain region and rain shadow region of Tamil Nadu recorded much higher rainfall than the previous year. Central India and the Gangetic Plains of Bihar, West Bengal and Jharkhand also recorded relatively higher rainfall than the previous year. Part of the far north-eastern region (i.e., Meghalaya) recorded lower rainfall than the drought year 2002. The day-1 forecast of the model was found to overestimate rainfall over Gangetic West Bengal, Bihar, Jharkhand, and underestimate heavy rainfall over western Ghats, Meghalaya and Assam (Figure 10a-d). Since the T80L18 model was noted to produce higher rain with the increasing length of forecast duration (i.e., day-3 and day-4 forecasts), better results were noted over regions where day-1 forecasts had underestimated.

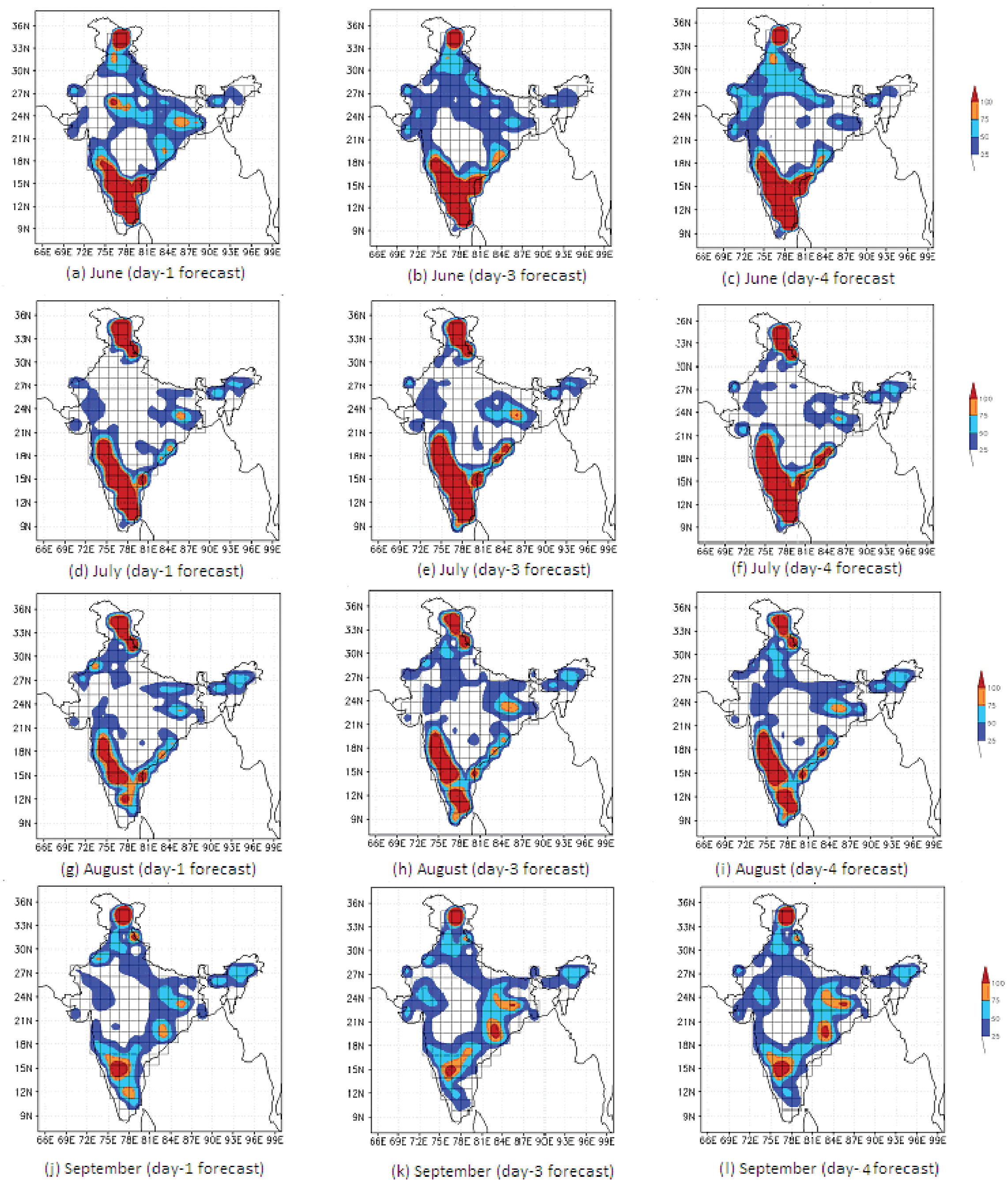

Figure 8: Subplots a-l show the percentage departure of monthly mean rainfall for day-1, 3 and 4 forecasts. Panel (a), (b) and (c) represent the same for day-1, day-3 and day-4 forecast, respectively, during the month of June. Similarly, panel (d -f), (g - i) and (j -l) represent the same for July, August and September, respectively.

Time Series of Average Observed and Forecast Monsoon Rainfall over India

All India average (i.e., 135 grid boxes) summer monsoon rainfall trend for three successive years from 2001 to 2003 are displayed in Figure 11. It provides the characteristics of inter-annual variation of daily rainfall distribution throughout the contrasting monsoon seasons of 2001, 2002 and 2003, as well as the performance of the T80L18 model in predicting monsoon rainfall with the increasing length of the forecast. It has already been stated that normal monsoon rainfall occurred in 2001 and 2003, whereas 2002 was reported as a monsoon deficit year. It was reported that in 2001, rainfall was normal in June, July and August, partially normal in

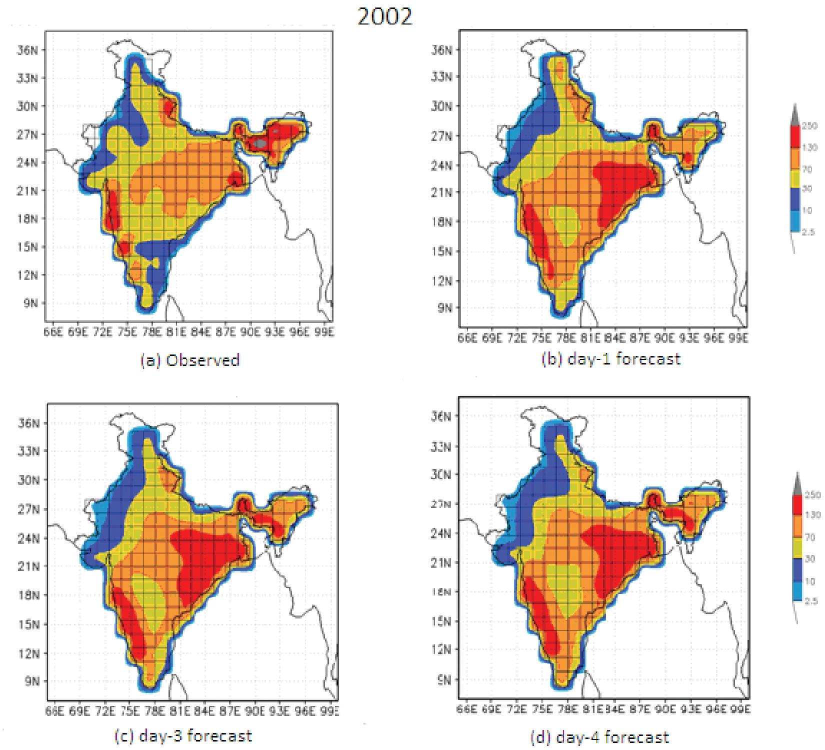

Figure 9: Subplots a-d represent the observed and forecast of monsoon rainfall distribution (cm) over India in the monsoon deficit year of 2002.

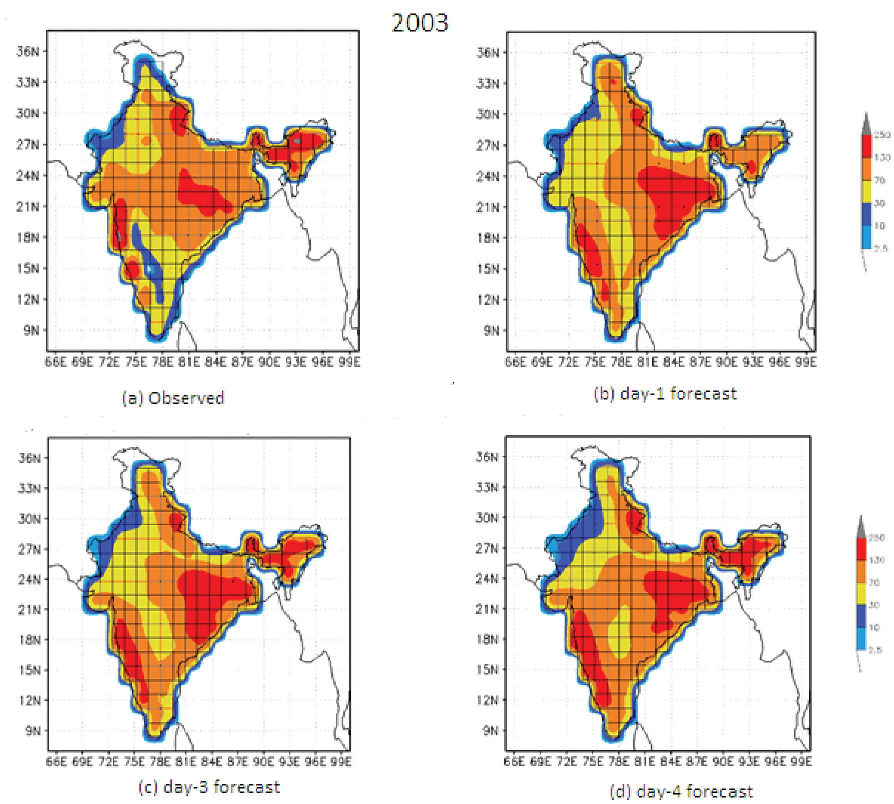

Figure 10: Subplots (a-d) represent the observed and forecast of monsoon rainfall distribution (cm) over India in the normal monsoon year of 2003.

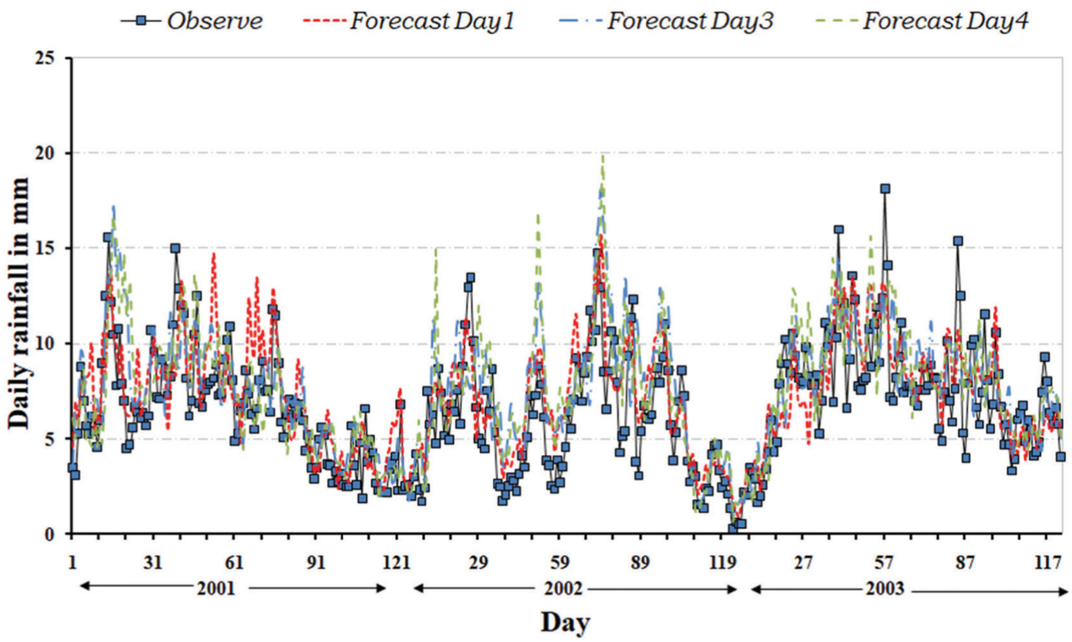

Figure 11: Time series of observed and forecast monsoon rainfall over 135 grid boxes of India for 2001, 2002 and 2003.

September. However, in 2002, rainfall was normal in June and August, semi-normal in September and extremely scanty in July. Moreover, the total seasonal rainfall of 2002 over India was 81% of its long term average. But, in 2003, rainfall was normal in June and July and a little deficient in August and September. The total seasonal rainfall of 2003 over India was 102% of its long term average (Dash et al., 2006).

It can be seen from Figure 11 that in 2001 rainfall was high (generally above 5 mm/day) during the first three months (JJA) of the monsoon season and rainfall intensity dropped below 5 mm/day in last month (September) of the season. In the case of the monsoon deficit year 2002, the observed rainfall was below 5 mm/day for July. In the case of the year 2003, it was found that daily rainfall distribution was quite high (above 5 mm/day) in July and August, even continuing to early September.

The pattern of variation of rainfall was well predicted by the T80L18 model for all the forecast lengths. However in general, the model overpredicted rainfall with the increasing length of the forecast. In a particular case for July and August of 2001, day-1 forecasts were overestimating compared to day-3 and day-4 retrospective forecasts (Figure 11). It was also noted that the model occasionally could not predict heavy rainfall. Though the model was able to capture the pattern of rainfall deficiency event quite well (such as July 2002), it was noted to over predict the rainfall at a regular interval.

Conclusions and Discussions

Although error propagation within the global climate model for extended-range forecast is high, long and medium-range forecast using a global climate model is highly anticipated for socio-economic reasons. However, despite many new studies on global model forecast verifications (Sharma et al., 2017, 2019), a detailed monsoon seasonal forecast verification from a global model over the Indian subcontinent for almost 8 years was seldom attempted. The T80L18 model is a second-generation spectral model used for operational forecasting by many meteorological agencies of the world. However, current updated spectral models are used in many countries for targeted forecasting, for example, the T574L64 model was used by Singh and Prasad (2017) to assess the impact of Megha-Tropiques SAPHIR radiances for global data assimilation. Similarly, Prakash et al. (2016) assessed the performance of a high-resolution NCEP-GFS (T1534) model for medium-range monsoon precipitation forecast; and Mukhopadhyay et al. (2019) assessed monsoon seasonal performance of T1534 model at 12.5 km spatial scale during 2016-2017. This study attempts to present the performance of a simpler global model by analysing some general characteristics with the increasing length of the forecast.

The generic inference from statistical forecast verification indicates that the model skill varies heterogeneously over space and deteriorate after 72 hours of initiation in time. The model output error is conspicuous for the northernmost India, desert of western Rajasthan, western Ghats mountain region and rain shadow region of peninsular India. However, the model performs better over central India. In case of the drought year 2002, rainfall is found to be overestimated by the model in low rainfall region (i.e., central India, part of north, west and east India), and is underestimated in high rainfall region (i.e. part of northeastern India, Meghalaya, Assam, Western Ghats). The model produces deficient rainfall when the rainfall intensity remains high and excess rainfall during the drought period.

However, a detailed study on the performance of the T80L18 model is necessary considering important meteorological features such as western disturbance, heavy rainfall during monsoon depression, etc. This study is supposed to help in further development of the global model in terms of improved physical parameterisation schemes for the prediction of Indian summer monsoon rainfall at a different space and time scale.

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